Mechanical Properties and Permeability of Sand Casting Moulds with Eggshells Binder

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ABSTRACT

This research aimed to analyse whether or not eggshell could be a potential addition to sand mould composition as a binding material together with bentonite. Different amounts of eggshell material, i.e. 4%, 7%, 10% and 3%, were added to each sample. This study was a type of pre-experimental design called the one-shot case study. Among all sand moulds under study, sample 3 10% ES in dry conditions had the highest tensile, compressive and shear strengths of 0.09 Kg/cm^2, 3.11 Kg/cm^2 and 1.13 Kg/cm^2, respectively. The results of the permeability test with heat treatment at 110˚C for 60 minutes showed that sample 3 10% ES had a permeability value of 178.3 ml/min.

Keywords: mechanical properties, permeability, sand mould, eggshell

I. Introduction

Metal casting is a work piece shaping method involving a series of process, i.e. melting the material through heating and pouring it into a mould to produce the desired shape in the work piece. To date, the use of sand moulds remains the most preferable option due to its low-cost feedstock, variety of sizes and compositions, and recyclability [12].

One of the most commonly used materials in metal casting is aluminium. According to the October 2015 World Economic Outlook (IMF), aluminium is ranked 3rd as the primary base metal, with a global sales value of USD 90 billion per year (Ministry of Industry of Republic of Indonesia, 2016). The most common form of metal casting is sand casting, where the sand mix is composed of silica sand, bentonite, water, carbon, and waterproof powder.

The binding agent used in sand casting is generally bentonite only. According to [9], bentonite is used extensively as a binder in sand mould production because it has the required properties, i.e. generating a high binding strength and turning into clay when wet and becoming hard when dry, hence easy to work with for mould making.

In this study, the binder consisted of bentonite and eggshell powder. Eggshells are dominantly used in beauty products and fertilizers because of its high levels of calcium; they have not been considered as a potential material in the foundry industry. The chemical content of eggshells represents 11% of the total egg weight, which is composed of calcium carbonate (94%), calcium phosphate (1%), organic matter (4%), and magnesium carbonate (1%) [7].

A study involving limestone as one of the binders used and found that this material had a calcium content beneficial as a binding agent [3]. Limestone was chosen since it could be hardened after being mixed with water.

II. Method

This study was a type of pre-experimental design called the one-shot case study, in which a group of subjects were given treatment and then observed [13]. The research design is presented in Figure 1.

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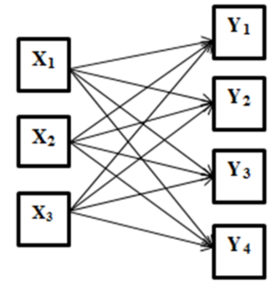

Fig. 1.Research Design

Where:

X_1 = 4% Eggshell and 3% Bentonite

X_2 = 7% Eggshell and 3% Bentonite

X_3 = 10% Eggshell and 3% Bentonite

Y_1 = Permeability

Y_2 = Tensile Strength

Y_3 = Compressive Strength

Y_4 = Shear Strength

The independent variables in this study were the ratios between silica sand and eggshells (X1, X2, X3) in the sand mould mixture, involving three different amounts of silica sand (88%, 85% and 82%) and eggshells (4%, 7% and 10%). 4. The dependent variables in this study are permeability (Y1), tensile strength (Y2), compressive strength (Y3), and shear strength (Y4). The control variables included 5% water, eggshells with a mesh size of 200 or fineness level of 0.02 mm and 3% bentonite mixed with silica sand with a mesh size of 40 or fineness level of 0.4 mm.

III. Results

Prior to testing the sand moulds, the eggshells were tested using XRD to determine the contents of elements in these additional materials. The results are presented in Figure 2 and Table 1.

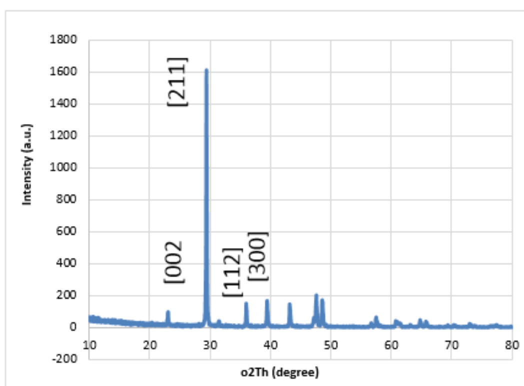

Fig. 2.Phase Identification of Eggshell Nanopowder without Sintering at 1100˚C

Table 1. Phase Identification of Eggshell Nanopowder without Sintering at 1100˚C

Pos. [˚2Th.]	Height [cts]	FWHM [˚2Th]	d-spacing [Å]	Rel.Int. [%]
29.4265	1606.40	0.1378	3.03541	100.00

Table 2. Properties of Eggshell Nanopowder from XRD result and Scherer Equation

Material	X-Ray Diffraction			
	Intensity (counts)	***FWHM (rad)***	***d-spacing (Å)***	***Crystallite Size (nm)***
Raw Eggshell Nanopowder	1606.40	0.1378	3.03541	59.7912

The results of XRD testing showed that the eggshell Nano powder not being synthesised and sintered at 1100˚C had a crystallite size of 59.7912 nm presented in Table 2. This is in line with the Hall-Petch law stating that the smaller the crystallite size, the harder the material [6].

A. Testing of Mechanical Properties

The strength of materials consists of:

1) Tensile Strength

Tensile strength refers to the maximum stress that a material can bear when being stretched or pulled before it fails.

2) Compressive Strength

Compressive strength is the capability of a sand mould to withstand the compressive force given by the flow of molten metal poured into the cavity moulded according to a pattern of the desired shape.

3) Shear Strength

Shear strength is the ability of sand to resist sliding forces. It is the internal resistance of the sand along the slide plane.

The compositions of sand mould samples in this study are as follows:

1. 4% eggshell, 3% bentonite, 88% silica sand and 5% water (sample 1 4% ES)
2. 7% eggshell, 3% bentonite, 85% silica sand and 5% water (sample 2 7% ES)
3. 10% eggshell, 3% bentonite, 82% silica sand and 5% water (sample 3 4% ES)

B. Mechanical Properties of Sand Moulds in Wet Conditions

Figure 3 shows the analysis results of the strength of each sand mould. According to [16], the strength of sand moulds in wet conditions could increase along with increasing bentonite content and reach the maximum value with a certain bentonite concentration. This suggests that the addition of different amounts of binder produces different strengths. As also stated by Herwido (2016: 79), the concentration of the binding material can make a significant difference to the strength of the sand mould.

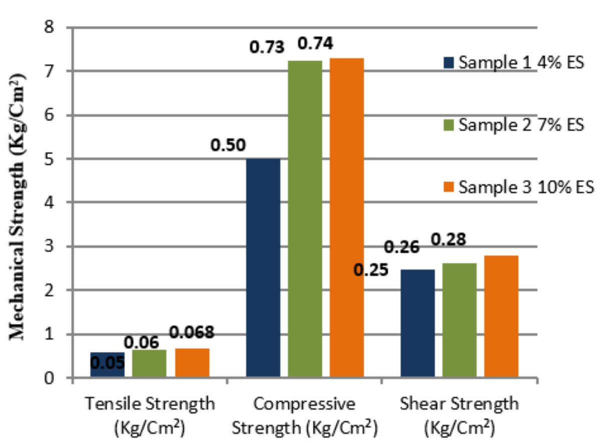

Fig. 3. Mechanical Properties of Sand Moulds in Wet Conditions

C. Mechanical Properties of Sand Moulds in Dry Conditions

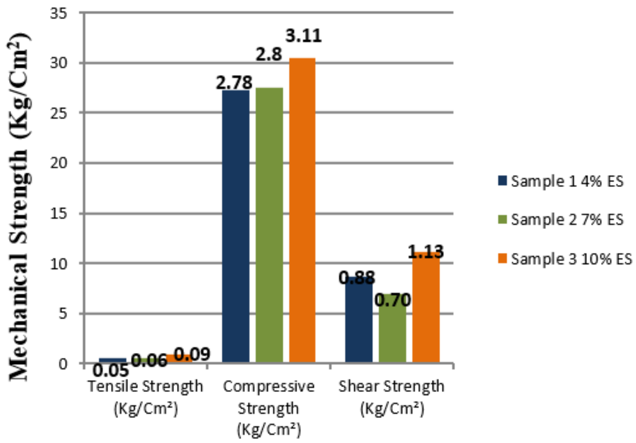

Fig. 4.Mechanical Properties of Sand Moulds in Dry Conditions

Among all samples, sample 3 10% ES had the highest tensile, compressive and shear strengths. The highest tensile strength was 0.068 Kg/Cm^2, but it is still below the predetermined standard of 0.07-0.42 Kg/Cm^2. The highest compressive strength was 0.74 Kg/Cm^2; this strength level has met the standard compressive strength ranges of 0.35-1.54 Kg/Cm^2. The highest shear strength was 0.28 Kg/Cm^2; this number is within the acceptable range of standards, i.e. 0.10-0.49 Kg/Cm^2. As a comparison, [8] conducted research on the mechanical properties of a sand mold composed of 85% silica sand, 10% bentonite and 5% water and found that it had tensile, compressive and shear strengths of 0.06 Kg/Cm^2, 0.54 Kg/Cm^2 and 0.022 Kg/Cm^2, respectively. In sum, this present study revealed that a mixture of 10% eggshell and 3% bentonite could reduce the use of excessive amounts of bentonite.

Among all sand moulds under study, sample 3 10% ES had the highest tensile, compressive and shear strengths shown in Figure 4. The highest tensile strength was 0.09 Kg/Cm^2, which is considered reaching the standard ranges of 0.07-0.42 Kg/Cm^2. The highest compressive strength was 3.1 Kg/Cm^2; this strength level has met the standard compressive strength ranges of 1.5-17.5 Kg/Cm^2. According to [11], the addition of limestone ($CaCO_3$) to concrete made of Lapindo mud had an effect on the compressive strength of concrete; the higher the concentration of limestone used, the higher the compressive strength. The highest shear strength was 1.13 Kg/Cm^2; this number is below the acceptable range of standards, i.e. 0.10- 0.49 Kg/Cm^2. Previous research conducted [15] revealed that a sand mould made of 10% bentonite, 82% silica sand and 5% water had tensile, compressive and shear strengths of 0.07 Kg/Cm^2, 1.2 Kg/Cm^2 and 0.5 Kg/Cm^2, respectively.

[2] pointed out that sand moulds composed of natural binders could be used to improve the mechanical properties of aluminium alloy casting. Moreover, [8] found that a sand mould composed of 85% silica sand, 10% bentonite and 5% water had a tensile strength of only 0.05 Kg/Cm^2, a compressive strength of 1.3 Kg/Cm^2 and a shear strength of 0.3 Kg/Cm^2. This present study revealed that a mixture of 10% eggshell and 3% bentonite could reduce the use of bentonite in the mixture.

D. Permeability of Sand Moulds

Permeability test is a test conducted to determine the capability of a sand mould to allow gas and steam pass through the sand mould. Casting defects occur because the optimal conditions are not met during the casting process [5]. Therefore, moulding sand with high permeability is essential to allow the escape of gases during the pouring of molten metal into the mould. [10] stated that the volume of air/gas passing through the sand mould should be determined using the permeability meter. The permeability value should not be too low or too high. All samples showed that 5% water was the optimum amount to bind well shown in Figure 5.

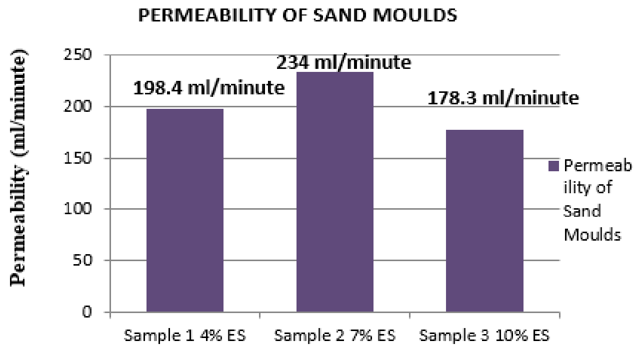

Fig. 5.Results of Permeability Testing on Sand Moulds

According [1], the low permeability of moulding sand results in difficulty for air to flow through the sand grains. As a result, when molten metal is poured, gas/air cannot escape and hence defects in the casting. Conversely, if the permeability is too high, the molten metal can enter into the gaps between sand grains, causing a rough casting surface.

The above explanation suggests that the excessive concentration of binding material can form smaller gaps between sand grains, making it difficult for air to pass through. However, if the amount of binder is too little, air can flow much more easily due to larger gaps. In this study, therefore, a low amount of binder resulted in large gaps in sample 1 4% ES and hence an easy flow of air through the sand grains. In contrast, sample 3 10% ES which contained a high concentration of binder had narrow gaps, causing difficulty for air to pass through the sand grains.

Previous research found that a combination of 5% bentonite and 5% Portland cement resulted in permeability of 176 ml/min [1]. In another study, a composition of 7% bentonite and 2% fly ash produced a permeability value of 231.67 ml/min (Herwido, 2016).

In general, sample 3 10% ES in dry conditions had the highest mechanical strengths but the lowest permeability although the value is slightly higher than the standard ranges of 50-170 ml/min.

In this study, therefore, the composition of sample 3 10% ES in dry conditions is considered the most suitable for metal casting. Sand moulds in dry conditions, in fact, have improved mechanical strengths because the water absorbed in the sand grain surface is removed. [14] further pointed out that the use of sand mixed with clay as the binder in dry conditions could generate higher permeability and strength than that in wet conditions. In addition to having high mechanical properties, sample 3 10% ES had a permeability value close to the predetermined standard value or range in metal casting. Therefore, the composition of sample 3 10% ES is particularly suitable to be applied for mould making in metal casting.

IV. Conclusion

The results and discussion above have led to the following conclusions. Among all sand moulds under study, sample 3 10% ES in dry conditions had a permeability value suitable for use in metal casting, i.e. 178.3 ml/min. Also, sample 3 10% ES had the highest tensile, compressive and shear strengths of 0.09 Kg/Cm^2, 3.11 Kg/Cm^2 and 1.13 Kg/Cm^2, respectively.

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